Psychological Monographs

General and Applied

No. 437
1957

Gradients of Error-Reinforcement in a Serial Perceptual-Motor Task

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Price $1.00

Vol. 71
No. 8

Edited by Herbert S. Conrad

Published by The American Psychological Association, Inc.

Psychological Monographs: General and Applied

Combining the Applied Psychology Monographs and the Archives of Psychology with the Psychological Monographs

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Vol. 71, No. 8 Whole No. 437, 1957
Psychological Monographs: General and Applied

Gradients of Error-Reinforcement in a Serial Perceptual-Motor Task[1,2]

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I. INTRODUCTION

THE primary problem of the present study was to determine whether a statistically significant gradient of response strength of errors around rewarded responses would remain after removal of the guessing-sequence and probability-bias factors by control groups directly comparable to the experimental groups.

Originally reported by Thorndike (16, 17), the "spread-of-effect" phenomenon has received substantial empirical verification. Considerable disagreement, however, has developed about its theoretical interpretation. Thorndike (16) regarded the gradient of decreasing intertrial repetition of errors with increasing distance from a rewarded response as strong evidence for the *direct* strengthening by reward of S-R connections. He saw it as an "independent proof" of his law of effect. More recent investigators have presented a wide variety of alternative interpretations. These range from the suggestion that the Thorndike effect is simply one special case of a more inclusive generalization-of-reinforcement principle (9) to the conclusion that the obtained gradients bear no essential relation to *reward* but are artifacts of such conditions as number-guessing habits and probability bias in the response series (3, 4, 14, 15).

The present study is an attempt to provide data on this problem with more adequate controls than have hitherto been used. The necessity for such controls is pointed up by the various studies which have shown that artifactual gradients can be produced under certain conditions in the absence of reward. However, the gradients that have been obtained under conditions designed to test the guessing-sequence and the probability-bias hypotheses cannot be directly compared with those obtained under the usual conditions of reward following motivation to learn. The evidence thus far obtained may be used to support the conclusion that these alternative factors can, under certain conditions, produce gradients; but these kinds of data cannot answer the question as to whether these factors are *necessary* or *sufficient* to explain the typical Thorndike gradients obtained within different experimental frameworks. These results do, of course,

[1] The data for this study were collected during the writer's period of employment as Research Psychologist at the Human Resources Research Center (now the Air Force Personnel and Training Research Center), Lackland Air Force Base, Texas. The opinions and conclusions contained herein are those of the author and are not to be construed as reflecting the views or the endorsement of the Department of the Air Force. A partial report of the study was given at the Chicago meeting of the American Psychological Association in September, 1951. (Abstracted in *Amer. Psychologist*, 1951, **6**, 293.)

[2] I am greatly indebted to Dr. Shinkuro Iwahara, for his assistance in supervising most of the statistical work, and to W. A. Hillix, for his assistance in the preparation of the manuscript.

throw suspicion on the Thorndike interpretation and point to the need for direct, controlled comparisons of the sort attempted in the present investigation. This problem is discussed at greater length in the recent review of the spread-of-effect literature (8).

II. Method

A. Subjects

Four groups of 300 basic trainees at Lackland Air Force Base were used. Two of these were experimental groups, E and EU; two were control groups, C and CRB. Data for the first two trials from an additional 74 *Ss* were also used for certain of the analyses, since these *Ss* were treated exactly like those of Group C, who had been tested earlier. This gave a pooled Group C of 374 *Ss* and a total of 1,274 *Ss* in the study.

All of the *Ss* were basic trainees from flights at Lackland Air Force Base between October 1950 and August 1951. They were all tested individually by the same airman, who was thoroughly trained as to the testing procedure but naive as to the purpose of the study. *Ss* were made available from the various flights according to the assignments worked out by the airman in charge of their distribution and were then placed in the various groups according to a mechanical system of rotation which was prepared in advance.

Throughout the study it was found necessary to discard only 20 *Ss*. Most of these eliminations were for some misunderstanding of the instructions or experimental error in test administration. These cases were discarded by *E* before the records were analyzed.

B. Apparatus

A SAM complex coordination Test, Form E (11), was modified in accordance with the requirements of this study. Only the aileron lights were used. A plywood mask screened off the elevator and rudder lights to avoid distraction of the *S*. The resulting display is shown in Fig. 1, which is a frontal view of the apparatus (not drawn to exact scale).

Movements of the stick from the central resting position to right or left were accompanied by the flashing on of the appropriate green lights in the lower row of lights. The middle light, representing the resting position of the stick, was not used. This left a total of 12 lights available for settings, 6 to the right and 6 to the left of the central resting position. The top row of red lights was used only as a signal. These lights were flashed on, as a group, for the "right" signal.

The normal tension on the stick was used. *S* was instructed to allow the stick to return to its central resting position as soon as he had made a response and had been given the right or wrong signal.

The rudder bar was fitted with a microswitch and wired into the control panel to make possible knowledge of results after each response. The *S* was instructed to push the rudder bar with his right foot immediately after making a light setting. Flashing on of all of the red lights in the upper row—the signal for right—or activation of a buzzer—the signal for wrong—then occurred as long as the bar was depressed.

A simple control panel was arranged for *E*, who sat at a table immediately behind the display panel. This consisted of a row of 12 lights corresponding to the 12 light settings available to *S*, and enabled *E* to observe *S*'s responses as they were made. A master control switch, silent in operation, enabled *E* to arrange the right or the wrong signal in advance of each response.

This apparatus made it possible to use all the data. In almost all the research thus far reported on this problem, response strength has been measured only by the percentage of repetition of responses (cf. 8). This all-or-none type of measure is more difficult to treat statistically and less sensitive than a measure in which tendencies toward repetition of response can be quantitatively scaled. Such a quantitative scaling was made possible in this study by using the variation, in linear light units, between settings made on successive trials. Use of this measure

was based on the assumption that the stronger responses would be less varied from one trial to the next, with exact repetition as the limiting case.

The task was also designed to minimize systematic pre-experimental response sequences of the sort which have been observed in the number-guessing studies and which have formed the basis for the guessing-sequence explanation of the Thorndike gradients.

C. Experimental Design

1. General Testing Procedure[3]

Instructions for both experimental groups and for the standard control group (C) were identical. Briefly, *Ss* were told that their task was to discover and remember the correct sequence in which to light the 12 lights in the row; that the settings would be called out by number, 1 through 12; that they would have only one chance on each setting; that they were simply to guess for the first trial since the sequence had been determined in an arbitrary, random manner, and systematic sequences of responses were therefore to be avoided; and that they could not expect to do very well at the beginning because of the difficulty of the task. Operation of the apparatus was then demonstrated, with emphasis on the proper use of the stick and rudder bar. Right and wrong signals were demonstrated. The *S* was required to tell *E*, in his own words, the essential parts of the procedure. Any aspects that seemed to be unclear were then reviewed by *E*.

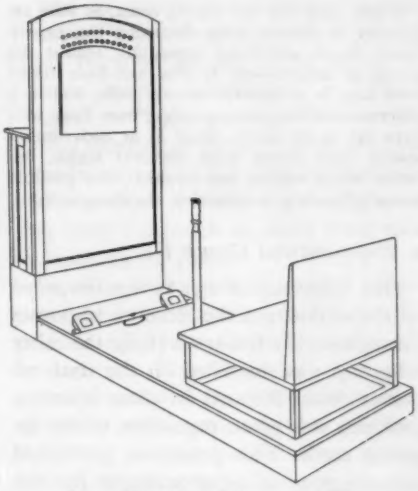

FIG. 1. Drawing of the apparatus.

After *E* was satisfied that *S* understood the general procedure to be followed he began the experiment. Light settings were called out as follows: "Setting No. 1," "Setting No. 2," etc. *Ss* were allowed to proceed at their own pace, although if an *S* was markedly slow he was cautioned to speed up his responses. The trials of 12 responses each averaged approximately 90 sec. A fixed intertrial interval of 30 sec. was used.

E was instructed to watch for any tendency towards systematic response sequences which *S* might show in spite of the strong caution in the instructions. Preliminary experimentation indicated that the most common examples of such sequences were the repetition of a single light position, with the apparent intention of eliminating it, and the progressive movement by one or more light units in one direction along the row of lights. *Ss* showing such obvious systematic sequences were cautioned by *E* when he was reasonably sure of the sequence, ordinarily after the third response in the series. This caution coming after the emphasis on this point in the instructions was so successful that only seven *Ss* had to be discarded for having persisted in making such systematic sequences of responses. These were discarded upon examination of the records prior to any scoring or analysis.

The special instructions given to the EU *Ss* at the end of the first trial, and the entirely different set of instructions given to the CRB group will be found along with the standard instructions (see footnote 3).

[3] The detailed instructions used for all conditions have been deposited, along with certain tabulations of data, with the American Documentation Institute. Order Document No. 5281 from ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C., remitting in advance $1.75 for 35-mm. microfilm copies or $2.50 for 6 × 8-in. photocopies. Make checks payable to Chief, Photoduplication Service, Library of Congress.

Before they left the testing room, *Ss* were requested to refrain from discussing the experiment. As an additional precaution against the giving of information, *Ss* who had been tested were kept in a separate waiting room, and in a different building when possible, from those who were yet to be tested. Since *Ss* at each testing session were drawn from different flights, between which contact was minimal, this possible source of passing information was disregarded.

2. *Experimental Group E*

One subgroup of 150 *Ss* was rewarded on the second and the eleventh responses throughout the five trials (E-2); the other subgroup was rewarded on the sixth response (E-6). Reward in these stimulus positions was given regardless of the response made. This procedure permitted measurement of error strength for the four stimulus positions *before* response 11 and the four stimulus positions *after* response 2; and for the four stimulus positions before and after response 6. The two subgroups were used to detect possible differences associated with serial position factors.

The primary concern was with the first two trials. However, additional prearranged rewards were given on the third, fourth, and fifth trials. This was chiefly to prevent suspicion and to keep up morale in the subject population in case there were any discussions of the procedure. Little use was made of these additional data.

3. *Experimental Uncertainty Group EU*

This was an added experimental group designed to determine the effect of the so-called "uncertainty" factor (cf. 8). These *Ss* were treated exactly like the standard experimental (E) *Ss* throughout the instructions and the first trial. At the end of the first trial, however, they were told that they would be informed during the second trial whenever the light setting they were about to make was one of those that they had responded to correctly on the first trial. They were then so informed, as the appropriate stimulus was given, but were not told the setting which had been correct on the first trial. It was believed that thus advising the *S* as to where in the response series he had been right on the first trial would effectively remove any uncertainty he might have on this point and thus eliminate deliberate repetition of responses near the rewarded-response position.

The EU *Ss* were divided into two subgroups of 150 each according to the position of the rewarded responses. EU-2 *Ss* were rewarded in the second and eleventh response position; EU-6 *Ss* were rewarded in the sixth response position. Unlike the E *Ss*, they were given only two trials.

4. *Control Group C*

This group consisted of 300 *Ss* who were given no rewards on the first two trials. Records from these two trials constituted the basic control data for comparison with the experimental results. On the third and fourth trials they were arbitrarily rewarded on the second and eleventh responses, making possible the accumulation of additional experimental data. One or two further arbitrary rewards were given on the fifth trial.

The additional 74 *Ss* from a control group originally designed for a separate purpose were treated exactly like the ordinary controls throughout trial 2 and therefore could be pooled with them for the important analyses based on trials 1 and 2. They differed from the standard controls only in the inclusion of an additional two nonrewarded trials, making a total of four such trials, before the first arbitrary rewards were given in the second and eleventh stimulus positions.

5. *Response-Bias Control Group CRB*

This group was designed to control for possible response biases due to the position of the rewarded response. These *Ss* helped to test the relevance of Smith's (15) hypothesis that gradients may be produced, as artifacts followed the repetition of a correct response, by the restriction in response range that occurs because of the tendency for *Ss* to avoid immediate repetition of a response. They also controlled for any pre-experimental biases in the response series, of the kind emphasized by Jenkins and Sheffield (4). Such biases needed to be considered even though the task was designed for relative freedom from them.

CRB *Ss* were individually matched with the standard E *Ss* on the basis of the particular light settings made by the latter in the critical, rewarded positions during the first two trials. They were forced to respond in this way by means of adjustable pointers, which were set immediately before each trial. In all other response positions they were allowed to respond as they pleased except for the usual caution against the use of systematic sequences. In order to make this procedure reasonable to the *Ss* they were told that operating checks were being run on the apparatus. Right and wrong were therefore not involved. Two subgroups of 150 *Ss* each (CRB-2 and CRB-6) were used, corresponding to the E conditions. They were given only 2 trials.

III. Results

In reading the results, it will be necessary to understand the meaning of several terms that are used repeatedly. "Stimulus position" and "setting number" will be used interchangeably to refer to *serial position* within a trial. That is, "stimulus position 6" refers to that position within a trial at which *E* called out "Setting number 6" and *S* subsequently made his sixth response in the series of 12 responses which constituted a "trial." "Light" or "light setting" refers to the *spatial location* of the particular response *S* made for any of the stimulus positions within a trial. *S* could make a light setting from 1 through 12, since there were 12 lights on the panel.

In the experimental groups "error position" generally refers to the stimulus position relative to the reinforced stimulus position. Thus the "+1" error position is the stimulus position immediately *after* the reinforced stimulus position; the "−1" is the position immediately *before*, etc. Responses made in the critical (rewarded) stimulus positions (second and eleventh, or sixth) are referred to as "key responses."

In the control groups, for purposes of comparison, error strength was measured before and after certain nonrewarded responses. These responses are therefore also called "key responses," regardless of their stimulus position. Other errors, before and after such key responses, are referred to as "+1," etc., as in the case of the experimental groups.

As earlier described, response strength was measured by the variation, in linear light units, between light settings made on the first two trials at a particular stimulus position. For example, if *S* responded with the sixth light on trial 1 in the fourth stimulus position, and with the third light on trial 2 in the fourth stimulus position, he was assigned an error difference score of 3 (6 minus 3).

A. Trial 1–Trial 2 Analysis

1. *All Ss*

This section presents the data from the 300 *Ss* of each major group. Marked after-gradients, but no fore-gradients,

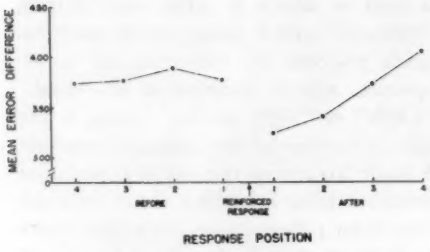

FIG. 2. Error-difference gradients in Group E.

were found for both experimental groups. These are shown in Fig. 2 and 3. Application of a trend analysis, using the technique of analysis of variance (5), showed that both of the experimental after-gradients were significant at well beyond the .01 level of confidence. The *F*s were 5.46 and 7.22 for E and EU groups respectively; 3.80 is required for 3 and 897 *df* at the .01 level.[4]

The reversed fore-gradient for Group EU in Fig. 3, which was in a direction opposite to the prediction, was not significant ($F = 2.47$; 2.61 required at the .05 level for 3 and 897 *df*). *F* was not calculated for the other curve, since there was no indication of a fore-gradient in the raw score means.

The corresponding curves for the two control groups are shown in Fig. 4 and 5. No evidence of any gradient was found in Group C. The gradient in Group CRB was very nearly statistically significant ($F = 2.58$; 2.61 required at the .05 level for 3 and 897 *df*). However, this is not as critical an analysis for the CRB Group as the analysis of the records of *Ss* who repeated the key response (the response made in the same stimulus position as the rewarded response for the matched E-group *Ss*), thus providing an "anchor" for their response biases.

The after-gradients were statistically significant in three of the four experimental subgroups but in none of the control subgroups. These data are available from the ADI (see footnote 3).

2. *Repetition of Key Responses*

The data were next analyzed according to whether or not the key (rewarded) response was repeated on the second trial. This analysis showed that the after-gradient in the experimental groups was dependent upon the repetition or near-repetition of the rewarded response. This is clearly shown by the three curves in Fig. 6. Here the 300 *Ss* of Group E have been divided into three subgroups on the basis of the amount of variation in the rewarded response from trial 1 to trial 2. It is apparent from the figure that gradients occurred following both exactly repeated and minimally varied rewarded responses. These were statistically significant at beyond the .01 level of confidence (*F*'s of 4.93 and 4.01; 3.83 and 3.94 required at the .01 level for 3 and 543, 3 and 135 *df*, respectively). No gradient occurred following a more extensive variation in the rewarded response. Again, there were no fore-gradients.

Similar results were found for a break-

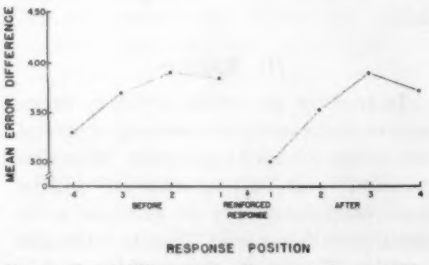

FIG. 3. Error-difference gradients in Group EU.

[4] Wherever necessary, Hartley's (2) suggestion for testing homogeneity of variance was applied. In no case was the ratio large enough to cause concern. Norton (12; see also 5) has pointed out that deviations from homogeneity cause smaller losses in accuracy than has been commonly supposed.

down of the EU data. With the exception of a slight inversion from position 3 to position 4, a regular after-gradient occurred following repeated rewarded responses. This was significant at well beyond the .01 level ($F = 6.93$; 3.83 required for 3 and 657 *df*). A perfectly regular gradient was also found following variations of one light unit in the rewarded response, although this was not statistically significant ($F = 1.27$; 2.65 required for .05 level for 3 and 177 *df*). No gradient was found following greater variations (2 to 11 units) in the rewarded response.

Detailed data for these breakdowns and corresponding data for the forepositions are available from the ADI (see footnote 3). The predicted gradients following repeated rewarded responses occurred for all of the four experimental subgroups, although they were statistically significant only for subgroups E-2 and EU-2. The fact that a highly significant gradient ($P = .01$) was found for Group E-6 following rewarded responses that were varied by one unit suggests that the gradients were not peculiar to an early serial position.

The curves of response strength following repetition of the key response in the two control groups are shown in Fig. 7. The 52 *Ss* represented are those from the C Group of 300 *Ss* who repeated either their second or their sixth response. The 182 CRB *Ss* are those who were matched with E *Ss* who repeated either their second or their sixth response.

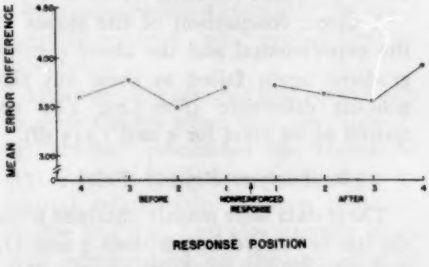

FIG. 4. Error-difference gradients in Group C.

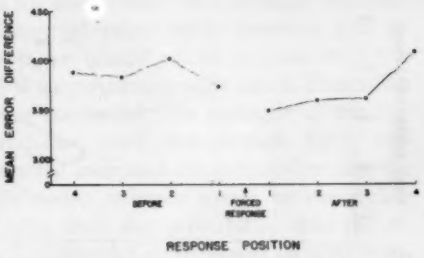

FIG. 5. Error-difference gradients in Group CRB.

No control gradients occurred. An analysis of variance for the CRB curve, which gave a slight indication of a gradient, showed that it was not significantly different from a horizontal straight line ($F = 1.93$; 2.62 required at .05 level for 3 and 543 *df*).

Although the gradient for the 182 E *Ss* who repeated the rewarded response was highly significant (beyond .01 level) and there was no gradient for the 52 C repeaters at the same positions, the direct comparison of the slopes failed to yield a significant difference ($F < 1.00$). The same was true for the comparison of the 182 E *Ss* with the 182 CRB *Ss* who repeated at the same positions ($F = 1.74$;

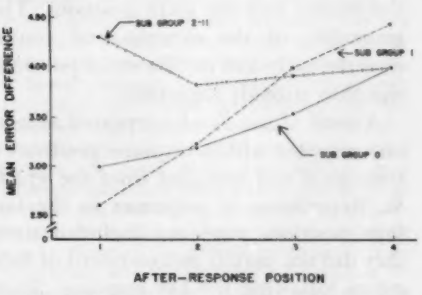

FIG. 6. After-gradients of error difference in Group E as a function of degree of repetition of rewarded response.

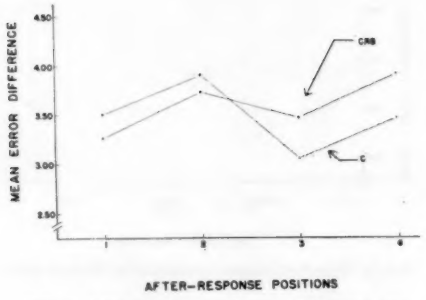

FIG. 7. After-gradients of error difference for control groups following repeated nonrewarded responses.

2.61 required at the .05 level for 3 and 1,086 *df*).

The CRB *Ss* who exactly repeated their key responses are those to whom the probability-bias hypothesis applies. The gradient for these *Ss* failed to approach significance. Both of the control curves presented in Fig. 7 were based upon repetitions of responses in positions 2 and 6 only. They thus provide an exact match with the position of the rewarded response in the two experimental groups.

A control curve based upon a larger sample was constructed for gradients following the repetitions of responses in any of the first eight stimulus positions. The use of such repetitions seems to be justified by the finding, noted above, that the experimental gradients occurred in both the second and the sixth positions. The generality of the experimental results over the early and middle serial positions was thus strongly suggested.

A total of 201 *Ss* who repeated at least one response within response positions 1 through 8 was obtained from the 374 C *Ss*. Repetitions of responses in the last four positions were not included since they did not permit measurement of four errors following the key response. Since for purposes of statistical analysis each *S* could be counted only once, it was decided that the first repetition of each *S* would be analyzed. Results for all of the repetitions were also computed, however, and are available from the ADI (see footnote 3). The response-variation values for this group of 201 C *Ss* showed some tendency toward an after-gradient because of the low error-difference score for the first error following the repeated response. However, the apparent trend did not approach statistical significance ($F = 1.16$; 2.61 required for the .05 level for 3 and 600 *df*). The inclusion of all of the repetitions of the 201 C *Ss* who repeated responses within the first eight response positions did not materially change the results.

As additional checks, in order that the first error score be tested independently of the trend test for a gradient, separate *t* tests were run between the mean variation score for the first error and that for each of the other three errors. None of the *t*'s were significant (values of 1.26, 1.75, and .59 for the comparisons with second, third, and fourth error means, respectively; 1.97 required for the .05 level).

For purposes of comparison similar *t*'s were run for the two experimental groups after repeaters. The difference in mean variation scores between first and fourth errors following repeated reward responses was found in each case to be highly significant (*t* for E = 3.52; *t* for EU = 3.76; 2.62 required for .01 level).

A direct comparison of the slopes of the experimental and the above control gradient again failed to show any significant difference ($F = 1.29$; 2.61 required at .05 level for 3 and 1,143 *df*).

B. Analyses Beyond Trial 2

These data were mainly obtained from the use of reward in positions 2 and 11, or 6, on trials 3, 4, and 5 for the 300 C *Ss*.

They were thus necessarily somewhat contaminated by interference from response biases carried over from trials 1 and 2. The gross results are available from the ADI (see footnote 3).

There was no gradient between trials 2 and 3. Thus reward only on the second trial of a pair did not result in a gradient. There was a very good gradient of error difference for trials 3 and 4. Continuing regular gradients for trials 4 and 5, and for repeaters on trials 2 and 3 in the E group, indicate that the gradients continued past the second rewarded trial. Although no statistical tests were used, owing to the relative impurity of the data, the consistency with which the gradients appeared is of some interest.

C. Tests of Alternative Explanations

A large number of additional analyses were run to test various alternative explanations of the experimental after-gradients.

Thorndike's hypothesis concerned only the presumed strengthening of an S-R connection by contiguity with reward. He assumed that this strengthening, established on the first trial, caused *Ss* to be more likely to repeat the same error to the same stimulus when the stimulus was presented again on the second trial. It might be argued that the simple demonstration of differences between experimental and control gradients is sufficient to validate Thorndike's hypothesis, since the control gradients eliminate the usual guessing-sequence and probability-bias hypotheses.

However, it is possible that reward acts in some fashion other than the "spread" or "scatter" postulated by Thorndike (17). Reward might create a stronger intratrial relationship between responses on the first trial, and also stronger intratrial relationships on the second trial. This would result in a stronger apparent intertrial relationship between first errors, yet would not be the kind of *direct* S-R strengthening with which Thorndike was concerned. For example, if the key response were the seventh light, and reward increased the probability that the *following* response would be the eighth light, then the probability that the error difference score would be zero (*S* responding with eighth light at the first after-error position on both trials) would be increased, independently of any actual strengthening of the S-R connection between environmental stimuli and the choice of the eighth light.

The analyses reported here were run to see whether an increase in intratrial relationships between responses actually occurred as a side-effect of reward; and, if so, whether this kind of response bias was sufficient to account for all of the observed intertrial strengthening. Only gradients following repetition of the key response are considered, since only in that case were significant gradients found. These analyses should therefore give some information about the degree of confidence that could be accorded the conclusion that the after-gradients were not entirely artifactual.

1. *The Alternation Hypothesis*

If *Ss* tended to respond first to one side, then to another, in this apparatus, gradients could be created artifactually by this tendency. The key response if repeated would serve as an anchor point on the same side on both trials. Alternation of the next response to the opposite side on each trial would then result in a lowered intertrial difference score for that response. This follows from the fact that if the response in any serial position was made to the same side on both trials, the maximum possible error difference was 5; if the response was made to different sides on the two trials, the maximum possible difference was 11. However, the alternation tendency could not explain why the experimental gradients following repetitions were stronger than the control, unless the alternation tendency was stronger in the experimental group.

TABLE 1

PERCENTAGE OF ALTERNATION AND MEAN ERROR-DIFFERENCE SCORES AFTER REPEATED KEY RESPONSES

Group	*N*	Trial 1	Trial 2	Error Differences
E-2	85	77.6**	67.1	2.55
E-6	97	57.7	55.7	3.37
EU-2	92	68.5	68.5	3.01
EU-6	128	78.9**	65.6	2.82
C	201	59.7	57.2	3.24
CRB-2	85	80.0**	63.5	3.41
CRB-6	97	80.4**	69.1*	3.05

* Significant at .05 level, compared with Control value.
** Significant at .01 level.

Table 1 shows this analysis for the first errors. The first chance repetition at any position from 1 through 8 was used for the C group (comparable data for all *Ss* are available from the ADI; see footnote 3).

Two of the four differences between experimental and control groups were significant at the .01 level on trial 1, and both of the differences between the CRB and C groups were significant at the same level. On trial 2, however, none of the experimental percentages were significantly higher than the corresponding control percentages.

The low alternation percentages for E-6 *Ss* corresponded to weak error reinforcements, but the highest alternation percentages, in the CRB group, also corresponded to weak error reinforcements. Thus alternation alone was apparently not sufficient to produce gradients in these groups. The last column of Table 1 shows these mean first-error difference scores.

Since these analyses were performed exclusively on *Ss* who repeated the key response, concurrence of either alternation (A) or nonalternation (N) on the two trials resulted in first after-errors on the same side of the central-rest position. Reversal of alternation or nonalternation condition on the second trial resulted in first after-errors on opposite sides of central rest. Accordingly, the *Ss* were divided into four classes on the basis of their alternation or nonalternation on trials 1 and 2. These were AA, NN, AN, and NA. The first letter designates whether or not *S* alternated sides from key response to first error on trial 1, the second letter on trial 2. For example, a *S* who made the key response on the left side on trial one, then the first error to the right on the same trial, would be classified with first letter A. As a repeater, he necessarily repeated the key response to the left on the second trial. Now, if he responded to the right on the trial 2 first error, he was classified in AA.

The gradients should not have differed significantly within any of the alternation classes if alternation gave rise to the gradients. That is, once the groups have been equalized with regard to alternation, the experimental treatments should not give rise to any significant differences.

Table 2 shows this breakdown. Classes AA and NN were combined on the basis of the fact that the response tendency was consistent on the two trials, resulting in first-error responses to the same side on both trials. In both classes, the error-difference score would tend to be decreased. A *t* test was run between the difference scores for C and E groups, and the difference was significant at the .02 level. However, when EU classes AA and NN were combined, the mean difference score for EU was exactly the same as that for C.

Classes AN and NA were similarly pooled. The *t* for C versus EU was significant at the .03 level, while that for C versus E was not significant.

Thus, when the alternation tendency was controlled by classifying the responses as outlined above, two of the four similar experimental groups showed significantly smaller difference scores after reward. Considering only these four comparisons, the chances of getting two of four *P*-values as small as even .05 by chance is only .015. This calculation gives some indication that there was still a difference between groups after the alternation tendency was controlled.

The same type of analysis into groups by response tendencies on trials 1 and 2 was performed for the CRB group, as shown in Table 2. No statistical tests were made of the differences between C and CRB groups, since inspection of the table clearly indicated that the differences would not be significant.

The alternation analysis gives some interesting information about subgroup E-6. This group showed a very weak error-reinforcement effect with its relatively high difference score for the first after-error of 3.37. This value was greater

TABLE 2

MEAN FIRST-ERROR DIFFERENCE SCORES AFTER REPEATED KEY RESPONSES FOR ALTERNATION CLASSES

Group	Same sides,			Different sides,		
	N	AA & NN	*t*[a]	*N*	AN & NA	*t*[a]
E	104	1.29	2.51*	77	5.31	1.19
EU	141	1.69	.00	81	4.98	2.23*
C (1-11)	148	1.69		92	5.74	
CRB	115	1.53		67	6.12	

[a] E and EU tested against C.
* Significant at .03 level.

TABLE 3

PERCENTAGE OF RESPONSES TO SAME AND DIFFERENT SIDES AFTER REPEATED KEY RESPONSES

Item	Group				
	E	EU	C (1-8)	C (1-11)	CRB
Total *N*	182	220	201	242	182
% Same Sides (AA & NN)	57.7	63.2	60.7	62.0	63.2
% Different Sides (AN & NA)	42.3	36.8	39.3	38.0	36.8

than that for any of the other experimental groups, and also greater than the control value of 3.22. However, when the group was broken down into components AA, AN, etc., none of the E-6 means were greater than those of the corresponding control groups. In other words, the alternation tendency worked against the tendency for errors to be reinforced in this group. The fact that the over-all score for E-6 was higher than for C is thus explained by the fact that the percentage of the group which either alternated or did not alternate consistently on the first two trials (AA or NN) was significantly smaller than in the control group ($\chi^2 = 6.89$, $P < .02$ for 1 *df*).

This brings up the possibility that the over-all gradients following repetitions in the experimental groups might be explained by a larger number of experimental *Ss* responding to the same side with the first error on trials 1 and 2. This would artificially reduce the difference score. Such a tendency would be shown by a larger number of experimental than control *Ss* appearing in classes AA and NN. Table 3 shows the percentages of *Ss* in each group who responded to the same and to different sides on the two trials.

The over-all difference among the proportions of E, EU, and C groups in classes AA and NN was not significant ($\chi^2 < 1.00$ for 1 *df*). This verifies what one might conclude from a gross inspection of the table: there does not seem to be any significant difference in the tendency to respond to the same side on both trials with the first error response. The over-all differences among groups are not explicable in terms of differential numbers of *Ss* who responded to the same side on both trials.

2. *The Central-Rest Tendency*

Even though it did not appear likely that there was any group difference in the tendency to respond to the same side with the first errors on the two trials, there remained a possibility that the reward affected the distribution of responses. A tendency was noted for *Ss* to restrict their response range following reward; this restriction would reduce the range of difference scores and might therefore have produced an artificial gradient.

In order to test for this possible central-rest tendency, responses were arbitrarily divided into "central' locations (light settings 4 through 9) and "peripheral" locations (light settings 1 through 3 and 10 through 12).

Table 4 shows the percentages of first errors following repetitions that were in central locations. Three out of four obtained experimental values were smaller than the control values on trial 1; EU-2 was significantly smaller. In spite of the fact that E-6 *Ss* had a significantly larger percentage in central locations, they did not show a significant error-difference gradient.

On trial 2, only EU-2 had a significantly larger value than the control. This shift from significantly smaller to significantly larger in group EU-2 was paralleled to some extent by a corresponding shift in EU-6, although the differences were not significant for this group. Altogether, it does not seem that the difference in percentages in central locations could have produced the gradients.

Further analyses were then run in order to compare the difference-score gradients following repetitions of *central* key responses with the gradients following repetitions of *peripheral* key responses. Central responses were again 1 to 3 units from the central-rest position, peripheral responses 4 to 6 units away. Table 5 shows these gradients and their *P*-values.

There were significant gradients following the repetitions of a central key response in the ex-

TABLE 4

PERCENTAGE OF CENTRAL FIRST-ERROR RESPONSES AFTER REPEATED KEY RESPONSES

Group	*N*	Trial 1	Trial 2
E-2	85	55.3	63.5[c]
E-6	97	68.0[a,d]	64.9[d]
EU-2	92	44.6[a]	76.1[b,d]
EU-6	128	50.0	67.2[d]
C	201	56.7	59.7
CRB-2	85	41.2[b]	52.9
CRB-6	97	52.6	51.5

[a] Significantly different from C value at .05 level.

[b] Significantly different from C value at .01 level.

[c] Significantly different from 50 per cent at .05 level.

[d] Significantly different from 50 per cent at .01 level.

TABLE 5

MEAN ERROR-DIFFERENCE SCORES AFTER CENTRAL AND PERIPHERAL REPEATED KEY RESPONSES

Group	*N*	After-position				*P*
		1	2	3	4	
E						
Central	108	2.75	3.08	3.71	4.30	.01
Peripheral	74	3.32	3.43	3.32	3.45	—
EU						
Central	135	2.69	3.70	4.10	3.57	.01
Peripheral	82	3.26	3.23	3.68	4.04	—
C (0 & 1)[a]						
Central	60	4.12	3.78	3.68	4.38	—
Peripheral	22	3.09	2.45	4.09	3.27	—
CRB						
Central	108	3.44	3.59	3.55	3.63	—
Peripheral	74	2.95	3.82	3.31	4.18	—

[a] In order to increase the small *N* for control repetition in positions 2 and 6, *S*s with a difference score of one were included.

perimental groups, but no other significant gradients. There was an interesting tendency for first errors after peripheral key responses to be stronger than after central key responses in the control group. This is the reverse of the situation in the experimental groups. This tendency was checked by tabulating the first-error strength after central and peripheral key responses over all stimulus positions for the control group. Seven of the eight positions checked showed a stronger peripheral error, with position five alone showing a stronger central error (data are available from ADI; see footnote 3). Thus this effect in the control group does not appear to have depended on the serial position in which the key response occurred.

Since there were these differences between the gradients following central and peripheral key responses, it is not true that a simple restriction in response range following *any* reward is adequate to explain the gradients. The remaining possibility is that there was a gradient of restriction of response range following reward of a central response, but not of a peripheral response.

This possibility was also checked. A different kind of gradient was calculated. This was a gradient of distances of the successive error responses from the central-rest position. The absolute distance from central rest, irrespective of direction, was used for this analysis. The error-difference score would tend to be reduced if responses were near the resting position, irrespective of whether the responses were to the left or right.

Table 6 shows that central-rest gradients were found in the two central subgroups, which had significant error-difference gradients. There was also a significant gradient in the EU group following peripheral key responses, but the gradient was in a reversed direction; that is, the response range was *less* restricted immediately following the key response than it was farther from it. These results suggest that there was some tendency to make the first after-error at about the same distance from the center as the rewarded response.

In general, the results were at least consistent with a hypothesis that the gradients were produced by a gradient in distance of the response from the central-rest position. It is impossible to evaluate from this analysis alone whether or not the central-rest tendency did actually produce the gradients. In the preceding analysis, the concern has been with the distribution of responses following reward. There was still a question of whether or not there was any tendency for errors to be strengthened directly, independently of such distributional artifacts. A method was needed which would be relatively independent of the distribution of responses following reward, yet which would reveal strengthening of errors. This method is next described.

3. *Intertrial Correlational Analyses*

The product-moment correlation was used to measure the degree of association between first- and second-trial first after-errors. This measure was chosen because the distribution of r is fairly

TABLE 6

MEAN TRIAL 1 CENTRAL-REST SCORES AFTER CENTRAL AND PERIPHERAL REPEATED KEY RESPONSES

Group	*N*	After-position				*P*
		1	2	3	4	
E						
Central	108	2.95	3.33	3.30	3.89	.01
Peripheral	75	3.52	3.23	3.20	3.12	—
EU						
Central	135	3.18	3.43	3.94	3.59	.01
Peripheral	82	3.86	3.15	3.12	3.24	.05
C(0 & 1)[a]						
Central	60	3.48	3.40	3.50	3.27	—
Peripheral	22	3.59	3.54	3.41	3.23	—
CRB						
Central	108	3.78	3.93	3.52	3.77	—
Peripheral	74	3.68	3.63	3.19	3.30	—

[a] In order to increase the otherwise small *N*, *S*s with an error-difference score of one were included.

insensitive to deviations from the normal bivariate distribution in the parent population (1, 13). The observed *r*, however, might have been produced by the relationship between the key response and first error on trial 1, in conjunction with a similar relationship on trial 2. These relationships can be partialled out of the final *r* through the use of partial correlation.

Correlations were computed between trial 1 and trial 2 first after-errors after key response, and between key response and first after-error on trial 1 and 2. Again, the analysis was only for *S*s who repeated the key response. Partial correlations were derived from these three correlations, so that the intratrial correlations were partialled out of the final correlation, which became a pure measure of intertrial correlation. Table 7 shows the results.

All the intratrial correlations were negative, although several were not statistically significant.

TABLE 7

INTER- AND INTRATRIAL CORRELATIONS AND PARTIAL CORRELATIONS FOR FIRST ERRORS AFTER REPEATED KEY RESPONSES

Group	*N*	Intertrial *r*	Trial 1 Intratrial *r*	Trial 2 Intratrial *r*	Partial Intertrial *r*
E					
After 2	85	.31[a]	−.46[b]	−.18	.26[a]
After 6	97	−.08	−.22[a]	−.17	−.12
Total	182	.13	−.33[b]	−.18[a]	.07
EU					
After 2	92	.30[a]	−.38[b]	.23[a]	.21[a]
After 6	128	.28[a]	−.52[b]	−.25[b]	.17[a]
Total	220	.28[b]	−.46[b]	−.21[b]	.21[b]
C	201	.11	−.01	−.01	.11
CRB					
After 2	85	.11	−.53[b]	−.24[a]	−.02
After 6	97	.36[b]	−.47[b]	−.25[a]	.28[b]
Total	182	.29[a]	−.50[b]	−.25[b]	.20[b]

[a] Significantly different from zero at the .05 level.
[b] Significantly different from zero at the .01 level.

TABLE 8

INTERTRIAL CORRELATIONS FOR FIRST ERRORS AFTER CENTRAL AND PERIPHERAL REPEATED KEY RESPONSES

Group	Central		Peripheral	
	N	*r*	*N*	*r*
E				
After 2	55	.39[a]	30	.30
After 6	53	−.03	44	−.07
Total	108	.20[b]	74	.07
EU				
After 2	59	.36[b]	33	.21
After 6	79	.21	49	.31[a]
Total	138	.28[b]	82	.25[a]
C (1–8)				
Total	143	.02	58	.28[a]
CRB				
After 2	55	.34[b]	30	.02
After 6	53	.23	44	.40[b]
Total	108	.28[b]	74	.24[a]

[a] Significantly different from zero at .05 level.
[b] Significantly different from zero at .01 level.

The negative correlations reflect the alternation tendency. In the control group, the intratrial correlation reflecting this tendency was negligible.

The difference between the control intratrial *r* for trial 1 and the *r* for the other groups was significant at the .05 level, or better, for groups E-2, EU-2, EU-6, CRB-2, and CRB-6. On trial 2, the same significance was found between control and EU-2, EU-6, CRB-2, and CRB-6. Since only *S*s who repeated were considered in this analysis, the differences were not produced by any artifacts due to differential repetition. Reward, as in the E and EU groups, or forcing, as in the CRB group, thus seems to increase the operation of response biases of the kind shown in intratrial correlation.

After the intratrial effects had been ruled out, three out of the four experimental subgroups still showed significant partial *r*s, indicating "pure" intertrial associations between first errors. However, a negative *r* was obtained for E-6, corresponding to its weak error-reinforcement. Thus, when this group was pooled with E-2 to get the total E, the correlation was actually smaller than that for the C group, though not significantly so. It is difficult to see why there should be such a marked difference between the second and sixth position subgroups in this E group. It was pointed out earlier that the alternation tendency worked against any error reinforcement in this group, but this tendency needs explaining also. In the absence of any evident explanation for this effect, an interpretation in terms of sampling variation cannot be rejected.

The control intertrial *r* and its partial *r* were both positive, but were not significantly greater than zero. The differences between the control partial *r* and the other partial *r*s were tested for significance, using the *z'* transformation method (6). None of the differences was significant. Thus the partial correlation technique failed to reveal any pure intertrial effects that differed significantly from E to C groups. It is still true that the obtained values of *r* in the experimental groups were significantly larger than zero, with the exception of the E-6 group.

An interesting incidental finding is that the intratrial *r*s were without exception smaller on trial 2. It may be that nonreward of the first after-error tended to weaken the tendency to make that response to the stimuli arising from the reward of the preceding key response.

Similar correlations were run between second, third, and fourth errors following the key response. The correlations were generally nonsignificant.

A further attempt was made to evaluate the intertrial correlation between first after-errors in terms of the central or peripheral position of the key response. Table 8 shows the results.

In general, the results were what might be expected on the basis of the central-rest analysis. The control groups showed a higher correlation following key responses in peripheral positions, while the experimental groups showed more significant results following key responses in central positions.

4. *"Mirroring" Analysis*

An apparent "mirroring" effect was observed in the experimental *S*s (E and EU combined). This was the tendency for *S*s whose key response and first after-error were on opposite sides of the center of the apparatus to respond about the same distance from the central-rest position on the two successive responses. For example, a *S* who responded with a no. 10 light for the rewarded response has gone 4 units to the right of the resting position. If he alternated sides on the succeeding response, he would tend to respond approximately the same distance to the left, that is close to the no. 3 light (4 units to the left of the central-rest position).

Evidence for this tendency is given by the correlations in Table 9. These correlations are in terms of the absolute distance from the central-rest position. There was a significant relationship between the key response and first after-error in the experimental groups on trial 1. In no case was a control correlation significant. These mirroring effects largely disappeared on the second trial.

This analysis is suggestive with regard to the failure to find significant experimental gradients following peripheral responses. As a result, presumably, of the mirroring tendency, a significantly larger proportion of such experimental *Ss* responded to the periphery on the opposite side following a rewarded key response on trial 1. Out of 31 *Ss* in Group C that had peripheral key responses and alternated their succeeding response, only 10 responded to the peripheral area. In the combined E and EU groups, 67 of 108 such responses were to the opposite periphery. This difference was highly significant ($\chi^2 = 8.72$, $P = .01$ for 1 *df*). The total number of peripheral first-error responses that followed peripheral key responses was also significantly higher for the experimental than for the control *Ss* (85 of 156, compared with 22 of 58; $\chi^2 = 4.64$, $P = .05$, for 1 *df*).

These differences are important because when the trial 1 first-error response was to the periphery, the intertrial difference score expected would be high unless there was again a mirroring effect on trial 2. Since the mirroring effect dissipated on trial 2, with a slightly higher proportion of control than experimental peripheral first errors, one would expect higher difference scores for experimental *Ss*. Thus the response biasing in terms of mirroring worked against intertrial error-difference gradients in the experimental groups. This point is of interest in indicating that response biases do not necessarily favor the production of gradients, or strong first errors, following repeated rewarded responses.

The strength of the mirroring effect, as indicated by the first-trial correlations in Table 9, suggests the possibility that it might be an important contributor to what has been described as the central-rest tendency in the experimental *Ss*. The greatest contribution to this tendency was made by *Ss* whose central first errors were alternated following central key responses. Mirroring and central-rest factors are obviously confounded in such central-central alternations.

In order to determine whether a genuine central-rest tendency remained when mirroring as a factor was eliminated, a check was made involving only nonalternating first errors. On the assumption of an independent central-rest tendency following reward, it was predicted that the proportion of nonalternating *Ss* shifting from peripheral to central would be greater than the proportion shifting from central to peripheral. This prediction was confirmed ($\chi^2 = 2.74$, $P = .10$ for 1 *df*, on trial 1; $\chi^2 = 8.16$, $P = .01$ for 1 *df*, on trial 2). The comparable checks for Group C and CRB failed to show the same effect, three of the four proportions being in the opposite direction and the fourth being very slight and nonsignificant ($\chi^2 < 1.00$).

It is thus concluded that the present study does provide independent evidence for the central-rest tendency as a side-effect of reward. Evidence for mirroring independent of the central-rest factor is of course also provided—by the significant peripheral-peripheral shifts described above.

The various intratrial comparisons made in the present section were based on summary data tabulations available from the ADI (see footnote 3).

TABLE 9

CORRELATIONS BETWEEN CENTRAL-REST SCORES OF KEY RESPONSES AND ALTERNATING FIRST ERRORS ("MIRRORING" EFFECT)

Group	First Trial					
	AA		AN		Combined	
	N	*r*	*N*	*r*	*N*	*r*
E	78	.15	44	.45**	122	.26*
EU	115	.46**	49	.32*	164	.41**
C	93	.09	47	−.09	141	.00
CRB	100	.11	49	.12	149	.10
Group	Second Trial					
	AA		NA		Combined	
	N	*r*	*N*	*r*	*N*	*r*
E	78	.21	33	.16	111	.19*
EU	115	.03	32	.25	147	.08
C	93	.15	44	−.24	137	−.02
CRB	100	−.01	23	−.05	123	−.10

* Significant at the .05 level.
** Significant at the .01 level.

5. *Combined Alternation and Central-Rest Analysis*

These analyses were an attempt to further analyze the gradients in terms of combinations of response-biasing effects. The first analysis concerns the percentage of each of the major groups within categories which tend to reduce the error-difference scores and within categories where the bias is toward increasing the error-difference scores. Groups AA and NN are again combined, since the first error was on the same side on both trials, and AN and NA are combined since the first error was to different sides of the central-rest position.

As is evident in Table 10, there was a relatively small difference in the percentage of each major group within each category. This indicates that the observed differences in gradients did not depend upon this difference in percentage of the group whose responses were biased toward low difference scores. For example, the percentage of

TABLE 10

PERCENTAGE OF *Ss* IN VARIOUS CENTRAL-PERIPHERAL AND ALTERNATION CATEGORIES

Group	*N*	Central			Peripheral		
		Same Sides (AA, NN)	Different Sides (AN, NA)	Total	Same Sides (AA, NN)	Different Sides (AN, NA)	Total
E	182	36.2	23.1	59.3	21.4	19.3	40.7
EU	220	40.0	22.7	62.7	23.2	14.1	37.3
C	201	42.8	28.3	71.1	18.4	10.5	28.9
CRB	182	13.2	46.2	59.4	7.1	33.5	40.6

the C group in the AA, NN, central category was larger than for either of the other groups, and this category should produce the smallest difference scores on the basis of the central-rest tendency and the alternation tendency per se.

The first-error scores actually found for each of the subgroups are shown in Table 11. There an interesting difference was revealed between the C and E groups. In the C group, the peripheral errors were strongest. In the E groups, the central errors were strongest, following reward. To check the effect further, special control data composed of repetitions by chance, not rewarded, in the E groups, were tabulated. As shown in Table 11, these repetitions were also followed by stronger peripheral errors.

Inspection of the distribution of central and peripheral first errors following central and peripheral repeated key responses suggests an interpretation of this result. On trial 1 the ratio of central to peripheral first errors was greater following a peripheral key response for the control *Ss*, and was greater following a central key response for the experimental *Ss*. This difference in proportions approached significance at the .05 level ($\chi^2 = 3.23$; 3.84 required for 1 *df*). A high proportion of central first errors would produce a natural bias towards lower intertrial error-difference scores, as has been shown earlier.

The greater tendency for peripheral key responses to be followed by central first errors in the control *Ss* is explainable on the basis of the relatively lower number of peripheral-peripheral alternating relationships (such as were apparently produced by the mirroring tendency in the experimental *Ss*), and the consequent opportunity for more or less random first-error responses to occur more frequently therefore in the central areas.

Table 11 also shows the *t* tests for the various combinations of first errors. Following central key responses, two of the four subgroup differences were significant. Both the combined analyses after central key responses approached significance. Since certain of the *t*s approached the accepted level of significance, their *P* values are given even though they were slightly greater than .05. Thus an analysis which controlled for

TABLE 11

MEAN FIRST-ERROR DIFFERENCE SCORES FOLLOWING CENTRAL AND PERIPHERAL KEY RESPONSES, ALSO CATEGORIZED BY ALTERNATION CLASSES

Group	Same Sides (AA & NN)			Different Sides (AN & NA)			Combined		
	Cent.	Periph.	Total	Cent.	Periph.	Total	Cent.	Periph.	Total
E	1.26	1.33	1.29	5.12	5.54	5.31	2.76	3.32	2.99
EU	1.50	2.00	1.69	4.76	5.32	4.98	2.68	3.26	2.90
C	1.73	1.45	1.63	5.89	5.38	5.73	3.39	2.87	3.24
E (C)[a]	1.64	1.58	1.61	5.94	5.10	5.64	3.92	3.18	3.63
EU (C)[a]	1.70	1.69	1.69	5.95	5.54	5.81	3.33	2.77	3.09
Group *t* tests									
E vs. C	2.12*	.47		1.44	.03		1.83	.82	
EU vs. C	1.08	1.84		2.71**	.53		2.37*	.74	

[a] E (C) and EU (C) refer to first errors after chance repetitions in the E and EU groups.
* Significant at .05 level.
** Significant at .01 level.

both alternation and central-rest factors still revealed differences at least approaching significance, and in some cases reaching it.

None of the comparisons showed a clearly significant difference following repeated peripheral responses. However, differences following peripheral responses were biased in the experimental groups as a function of the mirroring effects, as pointed out in the preceding section; they cannot be regarded as constituting a fair test of the spread hypothesis.

IV. Discussion

It is not possible, on the basis of the present results, to make a single simple and conclusive positive statement concerning the reality of error gradients after all of the possible artifacts have been removed. The critical experimental-control comparisons were not significant, even though the experimental gradients by themselves were generally significant for repeaters and the comparable controls were not.

On the other hand, a great deal of positive evidence was obtained in the various control analyses involving the first after-errors alone. For example, two of the four highly refined alternation-analysis results were significant at beyond the .05 level for the experimental subgroups. Three out of the four partial correlations were also significant for the experimental subgroups, in analyses that eliminated the distributional artifacts such as the central-rest tendency. Two of the four direct experimental-control comparisons in the final analysis combining alternation and central-rest factors were significant for the central rewarded responses. Moreover, it was shown that the puzzling failure of the experimental gradients to occur following repetitions of peripheral rewarded responses could well have been an artifact of the bias introduced by the "mirroring" effect. Of the major experimental-control first-error comparisons, only the partial *r*s failed to show some significant differences. Even here, three of the four subgroup differences were in the predicted direction.

The present experiment provides two additional important findings. One is that reward produces, as a side-effect, stronger intratrial relationships than nonreward. The second is that the experimental gradients seemed to depend on the repetition or near-repetition of the rewarded response.

On the assumption that the control analyses produced sufficient positive evidence to justify continued concern with the problem, an explanation of the Thorndike gradients in terms of both the reward and the repetition of key response factors was attempted. This hypothesis will be called the *serial response-response reinforcement hypothesis.*

According to the serial R-R reinforcement hypothesis, the repeated rewarded response plays a dual role in producing a gradient. It serves, first, to reinforce, through its reward (Thorndikian) action, the responses that follow. This takes account of the presumed superiority of repeated-rewarded over repeated-nonrewarded responses in producing gradients. Second, it serves as a constant element in the stimulus complex. This takes account of the apparent necessity for repetition of the rewarded response. Thus the S-R bonds, if Thorndike's terminology is used, are between successive responses, acting also as stimuli, as well as between environmental stimuli and responses, as Thorndike assumed.

This hypothesis differs from the original Thorndikian "spread" hypothesis and also from Tolman's (18) suggestion of reinforcement of blocks of responses in that it refers only to the *after*-gradient and that it assumes the dependence of this gradient upon the *repetition,* or near-repetition, of the rewarded response. The term "serial" is appended to indicate

specificity of reference to that kind of sequential response situation.

The present experiment affords some evidence which supports this hypothesis. The intratrial correlations were without exception higher following reward than following nonreward. There were stronger alternation tendencies following reward than were found in the control group. Central-rest gradients were found only following reward. All these lines of evidence indicate that following repeated rewarded responses, the responses of the *S* become more predictable. This is not simply a function of the fact that the response was repeated, since the key response was also repeated by the control *S*.

The CRB group is especially interesting in this respect. Here the *S* was forced to make a given response on both trials. The intratrial *r*s were especially high for this group; three of the four were significant at beyond the .01 level, and the fourth at beyond the .05 level. Yet there was no evidence of a gradient. This indicates the necessity of the Thorndikian type of strengthening to produce a gradient. Thus the CRB group gives further evidence that biasing of response sequences is not always sufficient to produce error gradients.

More direct support for the serial R-R hypothesis, which was admittedly *ad hoc* in the present study, has come from two subsequent experiments (7, 10) in which direct experimental-control comparisons have produced significant differences.

Certain incidental results of the present experiment have interesting implications and offer suggestions for further research.

The *central-rest tendency* consisted of a significant tendency for *S*s to reduce the magnitude of their response (amplitude of stick excursion from central-rest position) immediately following reward of a central response. Theoretically, this might be interpreted as indicative of an increased caution, or perhaps of increased relaxation, as a function of reward.

The *mirroring effect* consisted of a significant tendency for *S*s to match their rewarded response, in terms of distance of movement from the central-rest position, when the first after-error was made on the alternate side from the rewarded response. This effect was most prominent on the first trial. Theoretically, it offers some interesting support for the automatic effects of reward, since it can be explained in terms of an immediate repetition of a response following reward, if the response is now considered to be a movement of a certain magnitude from the central-rest position.

Practically, these effects may be of interest as possible biasing factors in the operation of complex controls.

Finally, Group CRB is of interest in that these *S*s, while generally not offering significant gradients, did show certain indications of "reinforcing" influences. Theoretically, the question here raised is the extent to which "forcing" of responses, as used in this control group, may take on "reinforcing" properties. The problem is related to the old theoretical one of the role of "exercise." This kind of forcing technique seems to offer certain advantages for the further investigation of the problem.

V. Summary

This study was designed to test the Thorndikian spread-of-effect hypothesis that errors are differentially strengthened as a direct function of their nearness to rewarded responses. More specifically, it was designed to determine whether statistically significant gradients of response strength would still be found after removal of the guessing sequence and probability-bias factors by control groups directly comparable to the experimental groups. Such direct experimental-control comparisons have not hitherto been made in the investigations purporting to show that gradients can occur in the absence of the usual reward.

Four main groups of 300 *S*s each were used. *S*s performed individually on a modified complex coordinator apparatus (11).

There were two experimental groups. In the standard experimental group *Ss* received one or two prearranged rewards, regardless of the particular responses made in the critical positions. The second experimental group included a control for "uncertainty" on the test trial. The standard control group consisted of 300 *Ss* given no reward for the first two trials. An additional 74 *Ss* were added to this group for most of the analyses. The second control group consisted of *Ss* who were individually matched with the standard experimental *Ss*. In the positions where experimental *Ss* were rewarded, these *Ss* were forced to make the same response. This group was designed to provide an additional check of the response-bias factors. The *Ss* were told that right and wrong were not involved since operational checks were being made on the apparatus.

The predicted after-error gradients were found in the two groups given reward. No such gradients were found in the control groups. No fore-gradients were found. The experimental gradients were found to depend upon the repetition, or near-repetition, of the rewarded response. Experimental gradients following repetition were significant, and control gradients following nonrewarded but repeated responses did not occur; but there were no significant differences between experimental and control gradients. There were, however, a number of significant differences between the strengths of the first after-error responses.

Possible distributional artifacts were controlled by using a correlation technique, which is relatively insensitive to changes in distribution of errors. These results tended to agree with the results of the analysis of variance of the gradients. The experimental correlations tended to be significant, and the control not significant, but the differences between experimental and control correlations were not significant.

Partial correlations were used to take out the intertrial correlations which might occur as a result of a concurrence of intratrial correlation between key responses and first error on the two trials. This was important because the intratrial relationships between the key responses and first after-errors were increased following reward or forcing, in nearly every case, compared to the observed relationship following repeated key responses in the control group. The partial correlations showed the same results as the gross intertrial correlations: three out of four significant partial *r*s in the experimental subgroups, no significant partial *r*s in the control group, and no significant experimental-control differences.

Although the apparatus was designed to be free of pre-experimental response biases, some interesting biases appeared in the experiment. First, there was a tendency for *Ss* to respond to alternate sides of the apparatus. Second, experimental *Ss* tended to respond closer to the center of the apparatus following reward of a central response. Third, those *Ss* who responded to alternate sides of the apparatus on the key response and the first after-error tended to respond about the same distance from center on the two successive responses. This "mirroring" effect was most apparent on the first trial. All these response biases were greater following reward.

Refined control analyses were done, controlling for both alternation and central-rest tendencies. Some of these comparisons of first after-errors reached significance, and others approached it. Significant differences were found only following repeated *central* key responses. The mirroring tendency worked *against*

gradients in the experimental groups following repeated peripheral key responses. This illustrates the important fact that response biases do not always work for the production of gradients.

It was concluded that no single simple and conclusive positive statement could be made concerning the reality of the residual experimental gradients after removal of the intratrial response biases. Nevertheless, there was sufficient positive evidence to justify continued concern with the problem. This evidence suggested a hypothesis, called the *serial response-response reinforcement hypothesis,* which postulates a dual role for the rewarded response. According to this hypothesis, it serves both as a constant element in the stimulus situation, thus increasing intratrial relationships, and as a direct strengthener of errors in the Thorndikian manner.

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(Accepted for publication February 4, 1957)